# Advanced testing of PV plants using portable SCADA tool

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ABSTRACT: The Performance ratio (PR) describes the technical quality of PV installation. On yearly basis, it is a good performance indicator for monitoring and comparisons of PV plants at different locations, but for shorter testing periods or commissioning, weekly -based or hourly-based indicators are preferable. We have developed a testing tool based on small SCADA which allows on-field measurements. The main advantages are flexibility and speed of testing. Thanks to the recent developments of "smart" sensors, the measuring tool can be adapted and reconfigured in accordance with the scale and type of equipment under test. Sensor data are collected and processed on site and performance indicators are extracted nearly in real-time. This report describes the methodology and practical experience in two application cases implemented in the frame of PV CROPS project.

Keywords: PV plant testing, On-site testing procedures, SCADA tools

## 1. INTRODUCTION

On-site testing of PV plants might be expensive and time-consuming task, since it is not conducted in controlled laboratory environments. It requires on-site test equipment, DC energy sources, transportation and personnel presence in remote locations at certain solar conditions and grid stability. The embedded monitoring systems provide databases for basic parameters. However, specific yield (SY) [kWh/kWp] and PR [%] are not sufficient indicators able to reveal system quality problems because of seasonal variation [1,2]. One possible solution for fast evaluation of PV performance can be a portable SCADA application installed on a field-ready laptop armed with precise DC/AC current and voltage sensors [3,4] as well as a meteo-station. According to the main focus of PVCROPS project, several testing kits have been implemented in order to bring the testing procedures beyond the current state of the art. The goal is M2M oriented applications and services to be developed defining the role of sensors, transducers, local area networks, gateways, servers in on-site PV installations testing.

## 2. PV TESTING CONCEPT

Some of the research challenges that appear might be related to the transition of merging the ICT/M2M subsystems into existing configurations of PV electricity generators. The testing engineers need to have testing tools design upon which real case problems are tackled and which should help to evaluate PV installations quality.

Facing this considerations, the motivation of this work is to develop and compare control mechanisms by tuning them with different approaches. General concept of the improvement of testing equipment is shown at Fig.1. In simple SCADA topology (case 1.), on-field computer/laptop plays the role of main server and data processing unit, while the communication link is single line, using one serial protocol and reading the sensors sequentially. In more complicated cases (case 2.& case3.), on-field datalogger/RTU collects the on-field data and re-send the packages in different intervals and

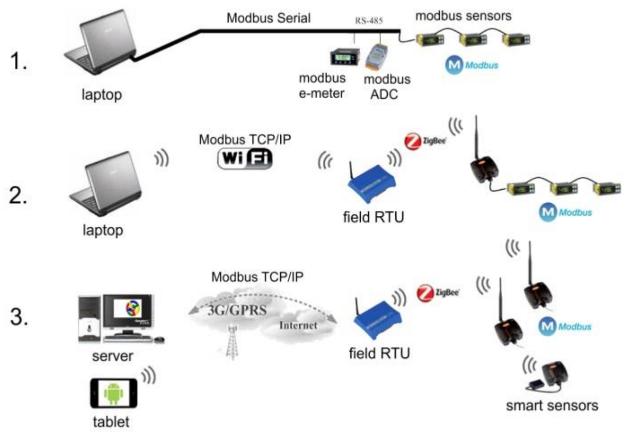


**Figure 1:** ICT over on-site PV testing concept.

communication channels to the remote main server. Small Zigbee or Wi-Fi networks or both, guarantee data transfer as well as additional personnel safety during the measurements. There is no need for on-field SCADA computer which could extend the duration of the testing.

The targeted functionality of these systems and testing architecture include several layers:

- Smart Metering, PV monitoring, SCADA dispatching, Drone inspection;
- Device API, Network API, Databases;
- Device management, Network Communication;
- WiFi, ZigBee, Bluetooth, HTTP, Modbus, CANbus;
- DC sensors, AC sensors, VIS and IR cams, environmental sensors.

The lowest physical layer devices can be any kind of heterogeneous sensors, meters, transducers, which comply with the requirements, related to measurement precision. The intermediate layers refer to the set of devices which provide communication to backbone field equipment: A/D converters, data loggers, protocol converters, etc., while the top two layers is a set of servers along with corresponding databases, dedicated software- APIs, data and graphics processing modules. In this sensor-rich architecture, the mobility of hardware and open-source software enables additional level of monitoring – precise daily dynamics of PV power generation.

## 3. DEVELOPED TESTING SOLUTIONS

As already mentioned, the proposed testing tool is a flexible combination of hardware and real-time control software (SCADA) applications. Several attempts have been made to construct an inexpensive portable environmental sensors head able to measure Solar GHI, PV module Temperature, Outdoor Temperature, Wind speed, and optional sensors for UVA+UVB radiation and atmospheric pressure. The optional sensors were arranged for measurements and future calculations of Air Mass and Ozone content [5]. Following the experience of UPM group [6] a small PV module (36 c-Si solar cells) was reconstructed and calibrated to perform solarimetric measurements. The aim of this design was the measurements to be close in optical spectra and dust conditions to regular PV plant modules. The other discrete sensors were selected according to their accuracy and market availability. All together were connected to the AI inputs of a precise 16-bit A/D converter, communicating with the SCADA app using Modbus serial interface. Later, the testing concept were enhanced by additional wireless layer of devices - 4-noks® Zigbee transmitters and sensors.

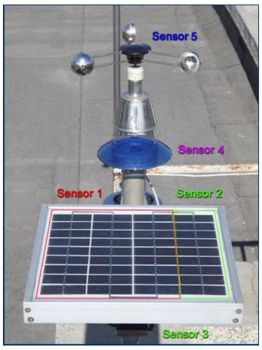


**Figure 2:** Environmental sensors mast.

Fig.2 gives an overview of the developed solutions. The other group of sensors, those for on-site electrical power measurements, need to survive in hostile conditions – high electrical fields, UV sunlight, high humidity etc. According to our experience, split-core current sensors and Hall-effect transducers suit best due to robust construction, high insulation strength, interference stability and quick montage. The SCADA measuring circuitry allows sensors to be changed and reconfigured depending on the type of equipment and required time intervals for testing. Some useful sensing devices are given at Fig.3. In Modbus communication infrastructure of point-to-multipoint topology up to 32 heterogeneous devices can be supported over a common serial bus for sensor data reading.

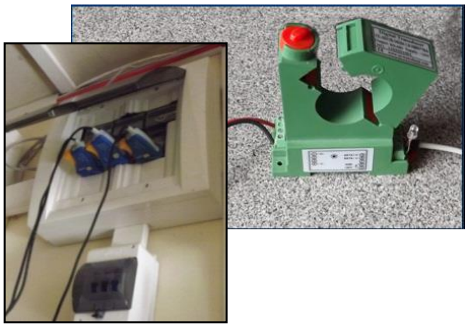

**Figure 3:** AC and DC current and voltage sensors.

It is important to point out that the next level of testing automation is the usage of wireless RF technologies. In our equipment, 4-noks® wireless smart sensors further enhances the flexibility and safety of on-field measurement [7,8]. The RF devices, engineered to operate within the Zigbee protocol, support the needs of low-cost, low-powered, self-configuring sensor network. Zigbee supports regular device addressing and a new application-layer addressing and data encryption.

Since the different generations of sensor hardware rely on different protocols for data transfer, the controlling SCADA software must accept, convert and present the field data into useful performance indicators.

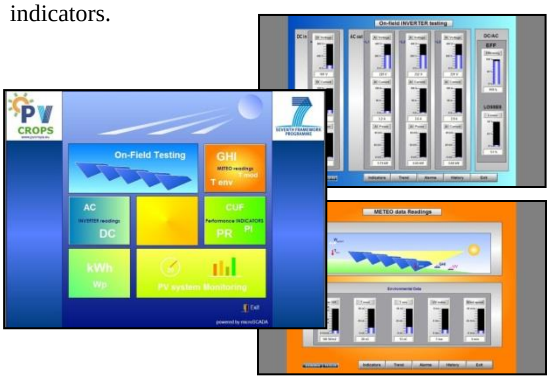


**Figure 4:** Portable SCADA based on Windows - control menus.

Two kinds of SCADA applications were developed for on-field testing: Windows-based and Cross-platform browser-based solutions.

To simplify testing, the Windows SCADA app is intended to be started on dedicated computer only. It is responsible for sensors reading, data processing and database logging, trending and reporting. It serves both as field PLC and server. The main control menus are presented at Fig.4. It is based on visual presentation, started on application flash player and beneath it a serial USB control layer communicating directly with the sensors.

This approach is useful for testing single inverters or several PV strings installed on PV rooftops or PV facades. When multiple string inverters have to be tested, connection boxes with dozens of PV strings or numerous MPPT inputs, then group/batch methods and a remote server is a better option.

Recent SCADA technologies offer pure Browser/

Server systems rather then ordinary Client/Server. Development of a new SCADA project now, seems to be similar to website development.


**Figure 5:** webSCADA application developed for cross-platform visualization

The webSCADA application, shown at Fig.5, has been implemented using newly developed IntegraXor HMI/SCADA software [9,10]. It is designed using web technologies (HTML, server-side and client-side Javascripts) to create a complete tool for building sophisticated and intelligent real-time systems. Our webSCADA is a server based application connected to internet for remote datalogging using serial port, GPRS or Wi-Fi communications. Communication Modbus TCP drivers and OPC server provide direct real-time readings from sensors, actuators or PLC controllers. A web-browser as a client is enough to view the content.

The IntegraXor app uses animated interactive SVG graphics for data visualization. The real power of open vector-based format is the possibility to generate charts and drawings directly viewed by all web browsers, including Safari and Chrome. This will facilitate the test engineers to exploit tablets and smart phones in their field work in PV plants monitoring.

## 4. EXPERIMENTAL

Two PV installations, 5 MWp PV plant and 200 kWp industrial PV rooftop, have been visited for tests in order the portable SCADA tool [11] to be validated in real-case conditions.

The central inverters of the first PV installation have been evaluated for a period of 3 consequent days when the GHI has varied in 0-780 W/m$^2$. First results have been obtained after 1.5 hours of equipment assembling. The average inverters efficiency is presented at Fig.6. The measured on-field value for 8 inverters is 96% and it confirms the expectations for smooth operation and uniform behavior in the whole power range.

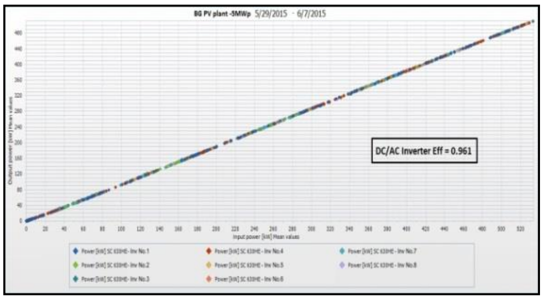


**Figure 6:** Example of measurement of inverters efficiency

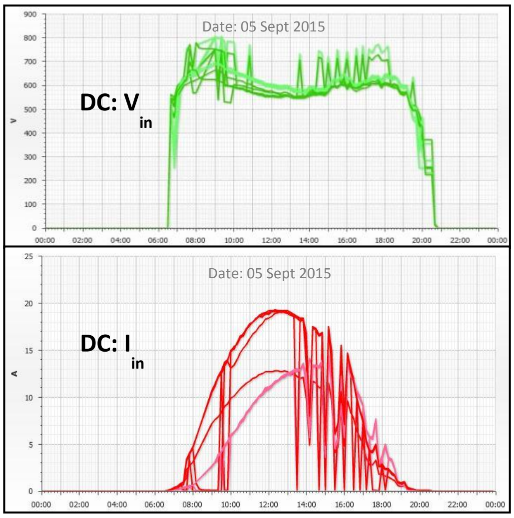


**Figure 7:** Example of six PV strings measurement

The second PV roof installation experienced much more fluctuations in parameters due to different positions of the monitored 6 PV strings on the roof - on East and West roof side. As can be seen on Fig.7, the max point of the generated PV strings currents differs in daytime depending on the roof inclination. Fluctuations due to clouds (in afternoon hours) passing above the installation have been observed even in the output voltage of the PV strings. The needle spikes around 14:00 are most dangerous for the equipment to recover because the fluctuation is nearly 95% of max power. The main problems which occurred during the equipment validation were sensors calibration and wireless antennas adjustment due to interference.

The collected performance data are compared to the embedded inverter monitoring. The scanning temporal resolution of the portable tool can be adjusted below the standard monitoring down to 1min. This ability allows quick power fluctuations to be monitored and investigated. The typical operating temperature (Fig.8) of the inverters positioned outdoor under shelter is nearly 60 $^{o}$C which is an acceptable value for modern DC/AC inverting devices.

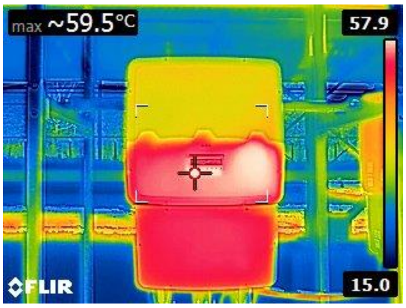


**Figure 8:** Inverter operation conditions

## 5. CONCLUSIONS

This paper describes portable SCADA testing kits for on-site measurements developed in EU PV CROPS project. Attention is paid to novel solutions for wireless transmission of sensor data.

The SCADA tools will allow testing of many aspects of utility-scale PV installations including future energy storage facilities.

The experiments confirm that on-field PV testing procedures could be improved further with more detailed measurents, enhencing the monitoring of PV generators and following the dynamics of environmental variations. In addition, some practical issues have been discussed along with some preliminary results.

This also demonstrates that despite some remaining problems in absolute accuracy, the collected information during PV testing reveals new possibilities for PV plants performance optimization.

ACKNOWLEDGMENTS

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# ADVANCED TESTING OF PV PLANTS USING PORTABLE SCADA TOOL

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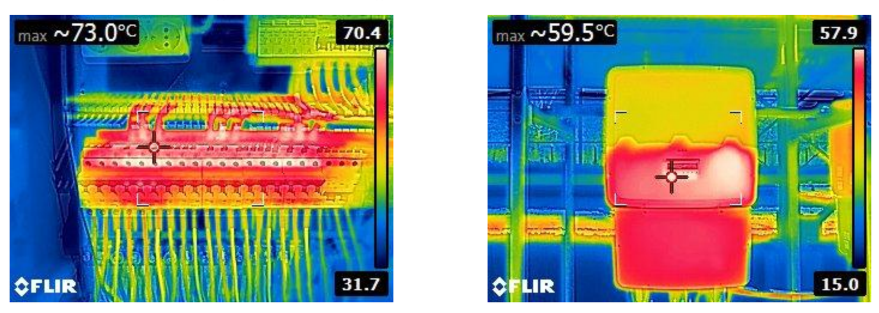
## Configuration

The proposed testing tool is a flexible combination of hardware and real-time control software (SCADA) applications. The measuring sensors can be reconfigured depending on the type of equipment and required time intervals for testing.

Environment &Electrical sensors

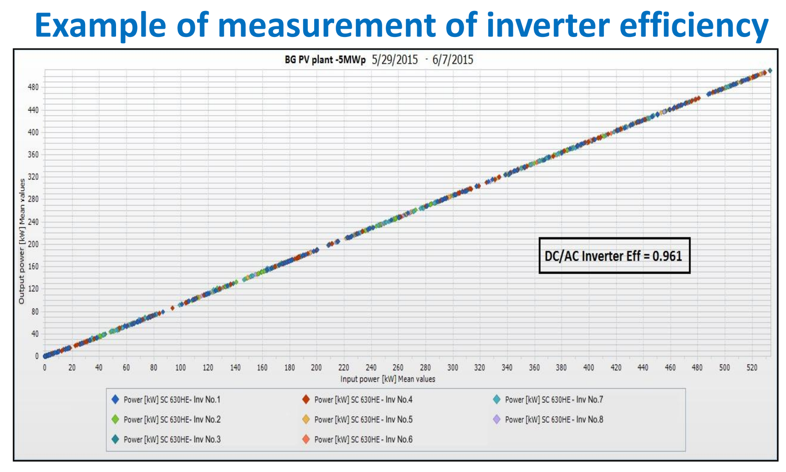
In order to understand the behavior of PV plant experiencing grid disturbances or device degradation, it is necessary to perform a series of tests, including IR images.



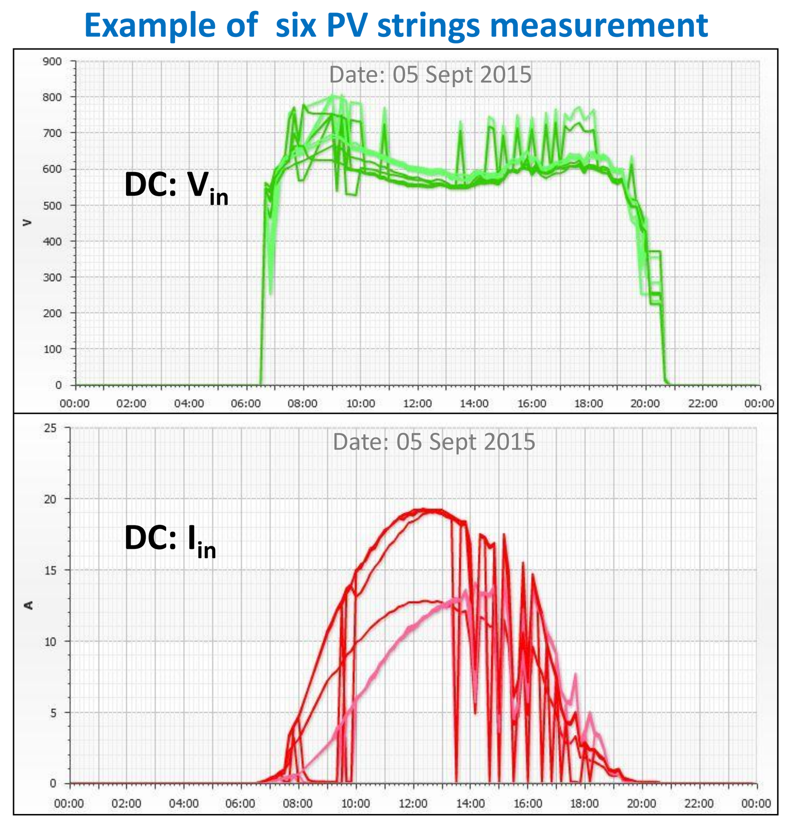
4-noks® wireless smart sensor technology further enhanced the flexibility and safety of measurement.

## Results

Example of measurement of inverter efficiency




Example of six PV strings measurement

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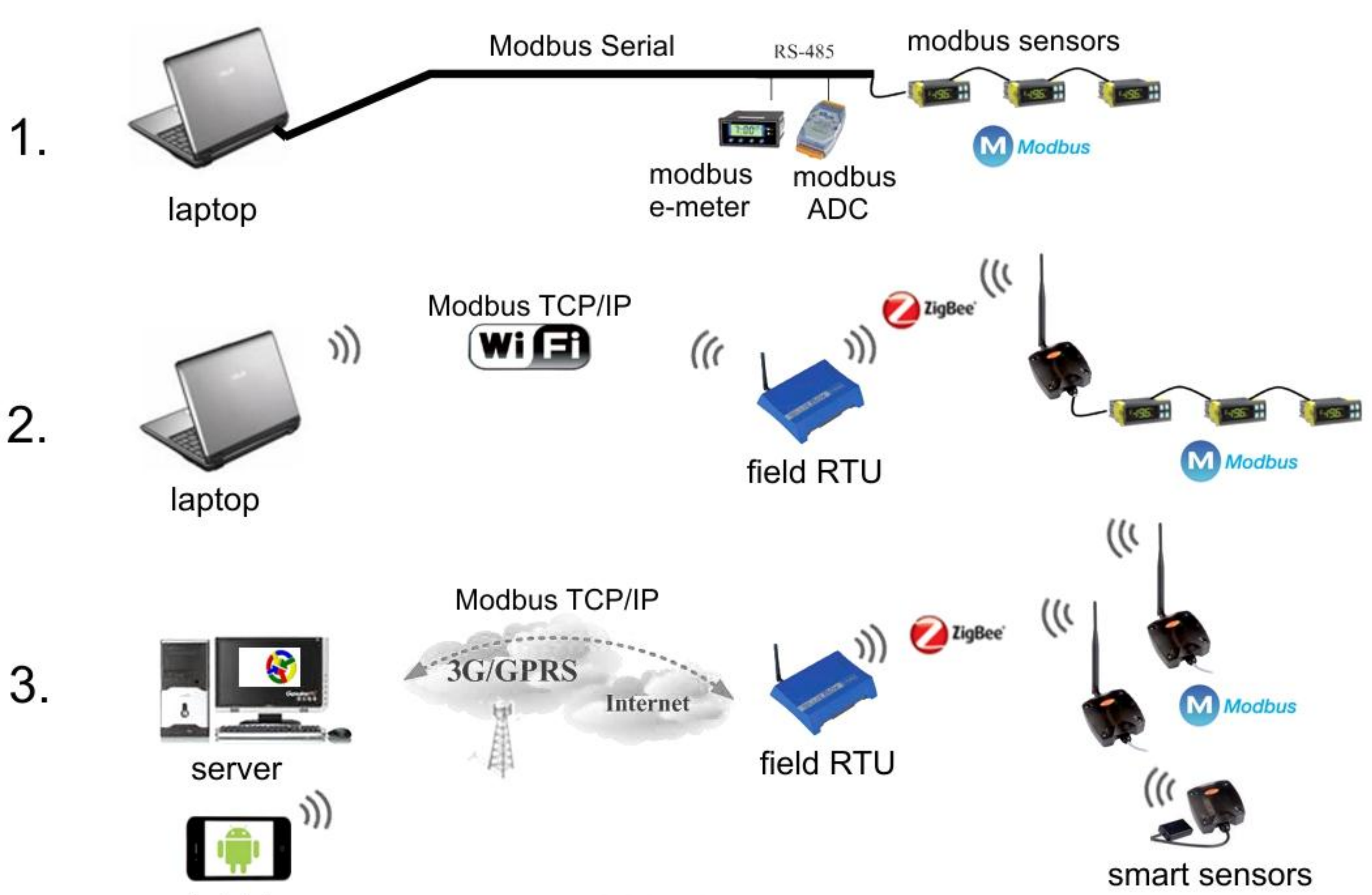
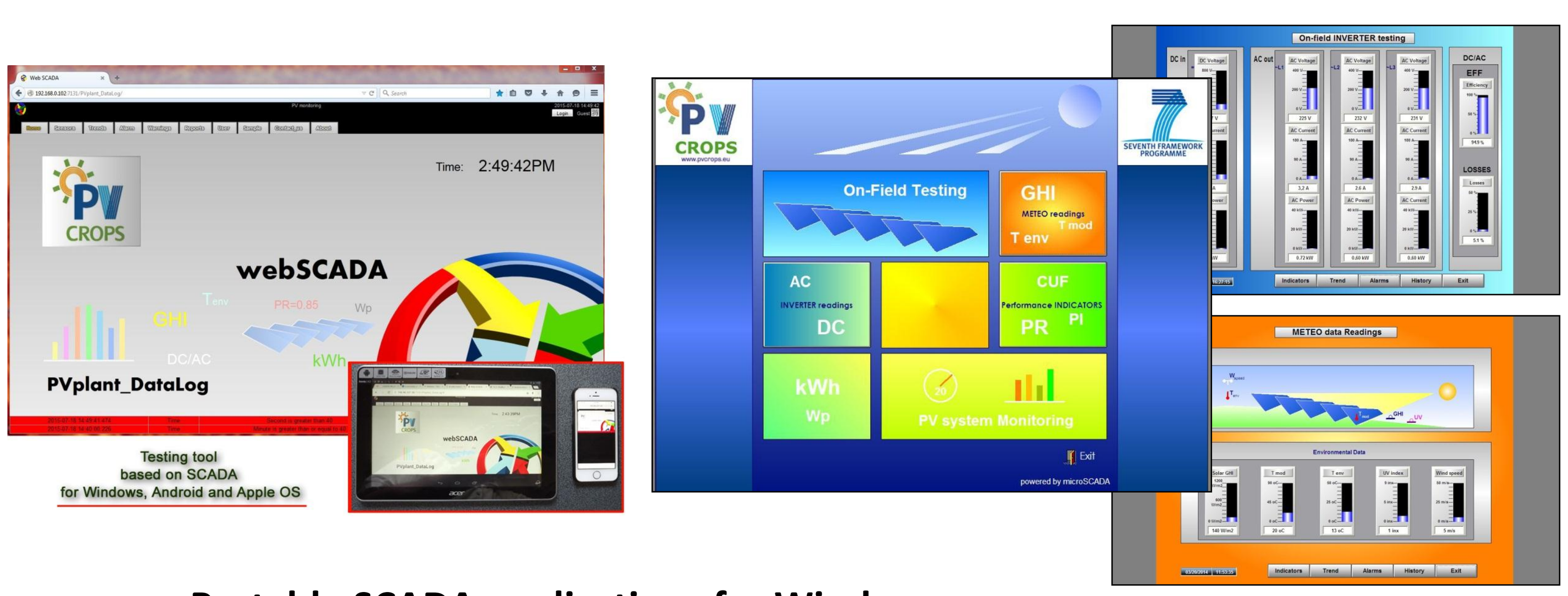



**Portable SCADA topology**




**Portable SCADA applications for Windows, and AndroidOS**

## Main Specifications

In simple SCADA topology (case 1.), on-field computer/laptop plays the role of main server and data processing unit, while the communication link is single line, using one serial protocol and reading the sensors sequentially. In more complicated cases (case 2.& case3.), on-field datalogger/RTU collects the on-field data and re-sent the packages in different intervals and communication channels to the remote main server.

The targeted functionality of these systems and testing architecture include several layers:

- Smart Metering, PV monitoring, SCADA dispatching, Drone inspection;
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## Experimental

Two PV installations, 5 MWp PV plant and 200 kWp industrial PV roof, have been visited for tests in order the portable SCADA tool to be validated in real-case conditions. First results have been obtained after 1.5 hours equipment assembling. The main problems which occurred during the validation were measuring sensors calibration and wireless antennas adjustment due to interference. The collected performance data are compared to inverter monitoring. The scanning temporal resolution of the portable tool can be adjusted below the standard monitoring down to 1min.

CONCLUSION

The portable SCADA tools will allow testing of many aspects of utility-scale PV installations including future energy storage facilities.

The authors wish to acknowledge the support of the EC, under the terms of FW7-ENERGY, project PV CROPS, contract No. 308468 for this research.